Chapter Four

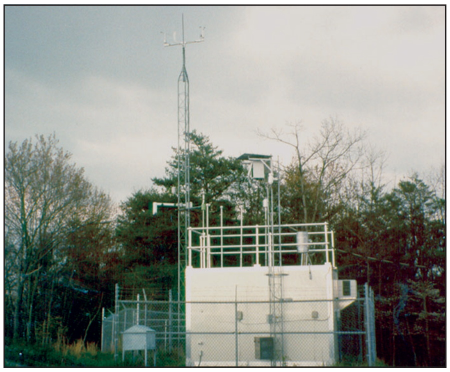
Great Smoky Mountains National Park -- Threatened by Air Pollution

Many national parks are being adversely affected by air pollution. One park facing the greatest threats from impacts of air pollution is Great Smoky Mountains National Park. As one of the Park System's "crown jewels," the preservation of the park's natural resources, including the elimination of existing air pollution impacts, is paramount to the park's resource management efforts. Great Smoky Mountains National Park encompasses over 520,000 acres in eastern Tennessee and western North Carolina, and is world-renowned for its prominent mountain ridges and deep-cleft valleys, its scenic beauty, and most notably, the incredible diversity of its plant and animal resources. It has more tree species than in all of northern Europe, and more species of vascular plants than any other North American national park. In fact, half of the old growth forest in the eastern U.S. lies within the park's boundaries. It also contains the headwaters for 45 watersheds containing over 2,100 miles of streams. Great Smoky Mountains has been designated as an International Biosphere Reserve and a World Heritage Site because of its worldwide significance.

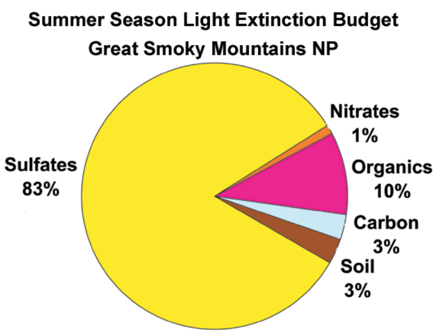
Air pollutants emitted from all kinds of sources (e.g., power plants, cars, trucks, and factories) located nearby and far away are degrading one of the park's chief natural resources—its air quality. Air pollution threatens the existence of many of the park's resources or significantly affects their condition, including its scenery, vegetation, streams, wildlife, and soils. Moreover, poor air quality diminishes visitor enjoyment of the park's renowned natural features and potentially affects public health. Burning of fossil fuels — coal, oil, and gas — produces oxides of nitrogen and sulfur, that convert to secondary pollutants (e.g., nitrate, sulfate, and ozone), that travel on air currents from all over the eastern U.S. As a result, Great Smoky Mountains National Park experiences some of the highest levels of these pollutants compared to any other national park in the East. The levels of some of these air pollutants have increased significantly over the past decade. Unless actions are taken soon to reduce air pollution emissions on a regional basis, the health and existence of the park's resources will continue to be threatened.

Views of Great Smoky Mountains on a clear and hazy day. Haze conditions result primarily from the light scattering associated with fine sulfate particles in the air. These particles are formed as chemical by-products of sulfur dioxide emissions from sources such as coal-fired power plants.

Great Smoky Mountains National Park was established on June 15, 1934; the park was designated an International Biosphere Reserve in 1976, and a World Heritage Site in 1983. View at Cades Cove, a popular park destination.



Air quality monitoring station at Look Rock, in Great Smoky Mountains National Park. Great Smokies has one of the most comprehensive air quality monitoring and research facilities within the NPS. Researchers often use the park to explore the many aspects of air pollution and its effects.



Various types of fine particles are responsible for the human-caused haze at Great Smoky Mountains National Park. Fine sulfate particles contribute over 80% to this haze during the summer, the season with the poorest visibility. Significant reductions in sulfur dioxide emissions from sources located in the Midwest and the southeastern U.S. are necessary to improve visibility conditions at the park.

Source: IMPROVE Program

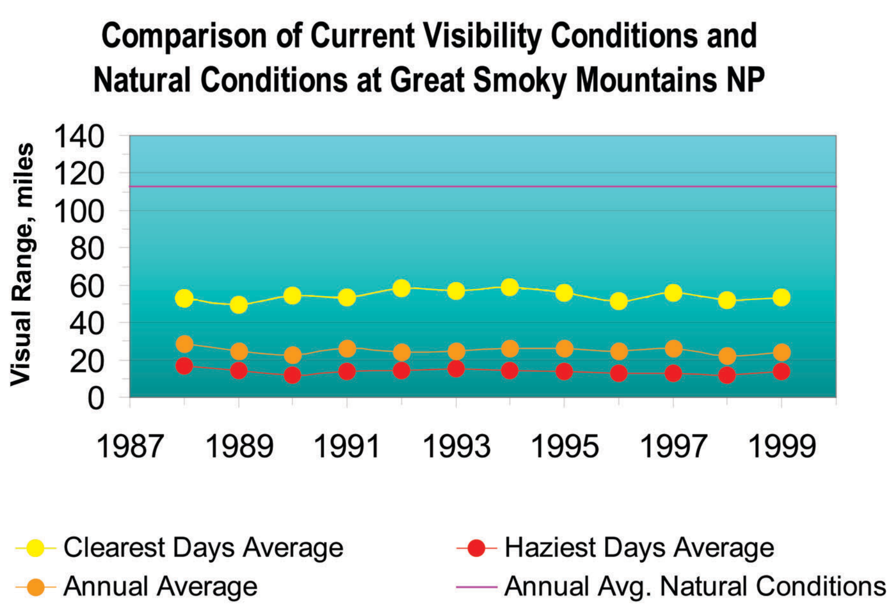
Resources under stress

Visibility impairment from regional haze

Good visibility in scenic areas like Great Smoky Mountains National Park has significant aesthetic and economic benefits. As evidenced by over 10 million visits in 1999, Great Smoky Mountains National Park has become the nation's most popular national park due in part to its accessibility and being within easy driving distance of two-thirds of the American population. It is estimated that these visits generate nearly a billion dollars annually for the local economy.

Views from scenic overlooks at the park have been seriously degraded over the last 50 years due to human-caused air pollution. Since 1950, based on regional airport records, average visual range in the southern Appalachians has decreased 80 percent in summer and 40 percent in winter. Summer used to have the clearest visibility, now it has the worst. This decline in visibility not only affects how far one can see from a scenic overlook, it also reduces how well one can see. Haze causes colors to appear bleached-out and obscures landscape features. Visible pollution typically appears as a uniform, whitish haze, different than the natural mist-like clouds for which the Great Smoky Mountains were named. In a survey, 74 percent of summer visitors to Great Smoky Mountains National Park said that clean, clear air was "extremely important" to them during their stay, and 84 percent said clear scenic views were "extremely important".

Increasingly, visitors no longer see distant mountain ridges because of this haze. Scenic views are impaired 90 percent of the time by human-caused air pollution. As shown in the figure below, current annual average visibility at Great Smoky Mountains National Park is 25 miles—much less than the estimate of natural visibility conditions, (113 miles). Current summer average visibility is 15 miles—it should be 77 miles in the absence of human-caused air pollution. During severe haze episodes, visibility has been reduced to less than 2 miles. Summer sulfate concentrations between 1988 and 1999 have increased 17 percent. Declining visibility is well correlated with increasing ambient sulfate concentrations. Fine particle sulfates, are the principal causes of the human-caused hazes at the park, as well as throughout the eastern U.S., as illustrated in the figure at left, which also identifies the other chemical constituents of fine particles that contribute to summer visibility impairment. It is primarily the burning of high-sulfur coal in eastern power plants and industrial facilities that produces sulfur dioxide emissions that are transformed in the atmosphere into fine airborne sulfate particles.



Visibility conditions, in miles, at Great Smoky Mountains National Park, have not shown improvement from 1988 through 1999. The annual average of 25 miles is very much less than the estimated natural conditions of 113 miles. Even the average of the clear days is far below natural conditions.

Atmospheric deposition impacts to terrestrial and aquatic ecosystems As shown in the figure below, Great Smoky Mountains National Park receives some of the highest rates of nitrogen and sulfur deposition of any monitored location in North America. These pollutants fall to the ground not only as acid rain and snow, but also as acidic dry particles and cloudwater. The acidity (pH) of annual precipitation measured at Great Smoky Mountains National Park, as part of the National Atmospheric Deposition Program (NADP) is 4.5, 5-10 times more acidic than natural rainfall whose pH ranges between 5.0 and 5.6. Cloudwater acidity averages 3.5 pH and has been measured as low as 2.0 pH. These acidic clouds bathe the high elevation forests during much of the growing season. Ninety percent of clouds sampled during a three-year period at the park were found to be acidic. Almost 33 percent of nitrogen and 50 percent of sulfur deposition to the park's high-elevation ecosystems results from clouds. As illustrated in the figure at the top of the next page, concentrations of sulfate, nitrate, ammonium, and hydrogen ions in clouds have increased since 1995.

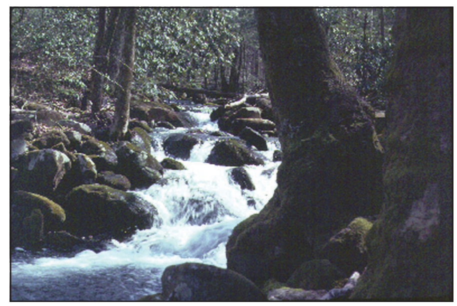
Great Smoky Mountains National Park contains 74 percent of the spruce-fir forests in the southern Appalachians, the largest remnant red spruce-Fraser fir ecosystem in the world. The park's spruce-fir forests are undergoing greater stress, which is thought to be the result of atmospheric deposition inputs to forest soil-water chemistry.

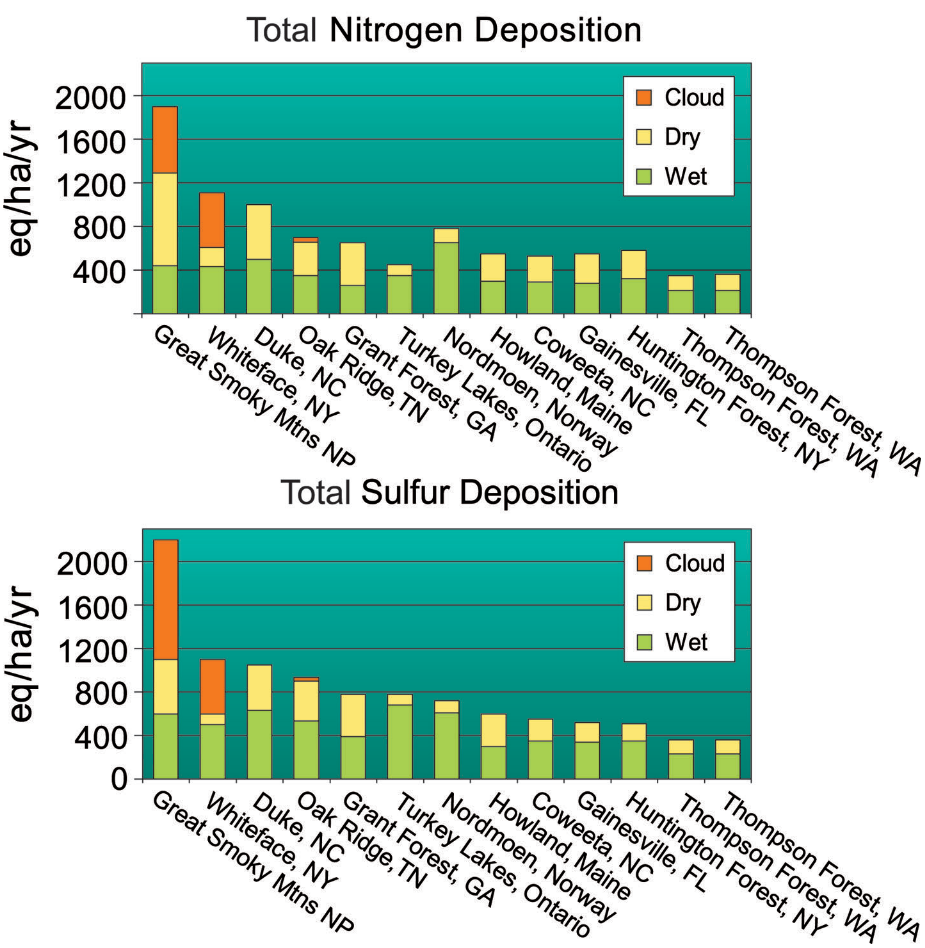
Research shows that both chronic (long-term) and episodic (short-term) acidification are adversely affecting sensitive streams and soils. Most high elevation park streams and soils are highly sensitive to acidification with little ability to neutralize acids resulting from nitrogen and sulfur pollution. Certain high elevation soils are receiving so much atmospheric nitrogen that they are suffering from advanced stages of nitrogen saturation. This condition limits the availability of forest nutrients (mainly calcium) to plants

Acidic Deposition Impacts on Streams at Great Smoky Mountains

Nine of ninety streams sampled over an eight-year period at Great Smoky Mountains had median pH less than or equal to 5.6, the lower limit of brook trout population viability. Stream water acidity increased significantly over this period.

Nitrate and sulfate levels, and acidity in streams increase with increasing elevation. Higher elevation streams also have less ability to neutralize acidic deposition, and thus, are more at risk.

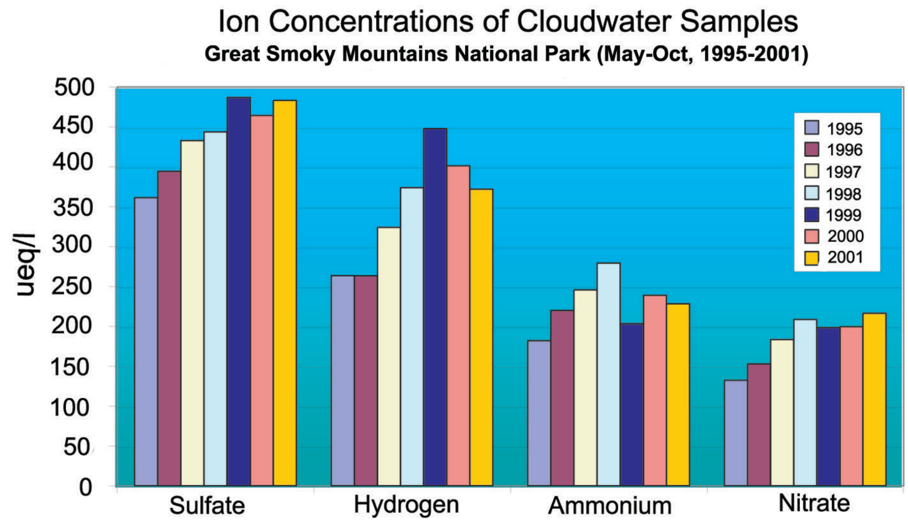




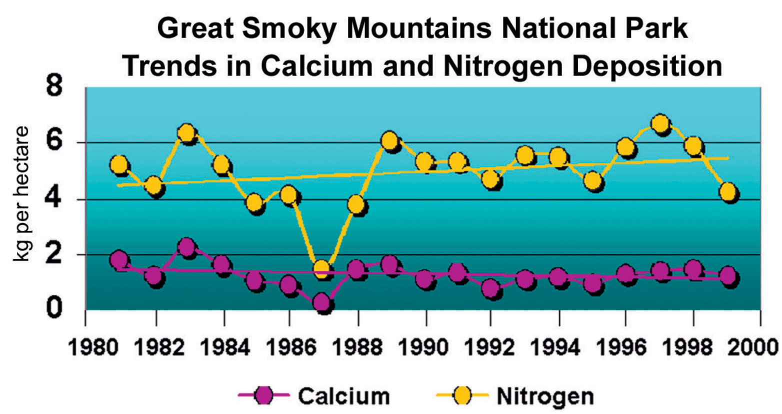
Total nitrogen and sulfur deposition at Great Smoky Mountains National Park compared to other locations worldwide. The park experiences some of the highest atmospheric deposition levels on the North American continent. One hundred equivalents per hectare is about 1.2 pounds per acre of nitrogen and 2.8 pounds per acre of sulfur.

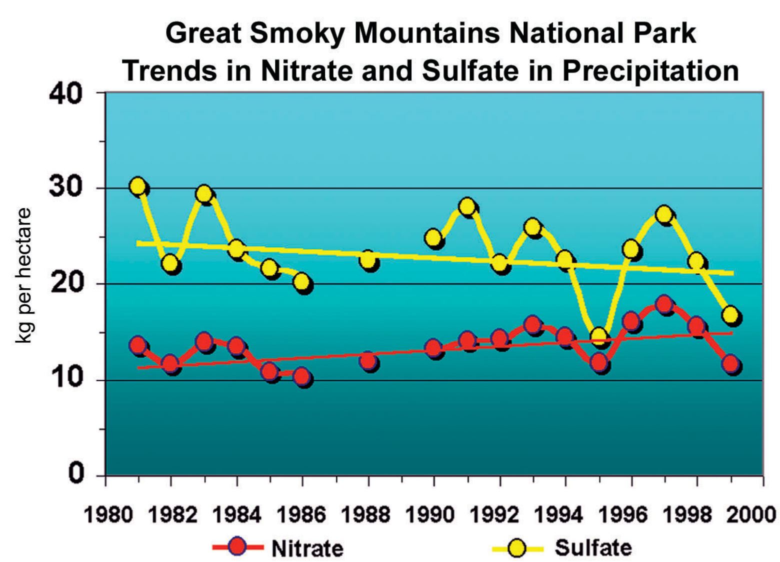
Source: Integrated Forest Study

Cloud samples taken annually from May through September at Great Smoky Mountains National Park show rising levels of several chemical constituents. The park partners with Tennessee Valley Authority and EPA to investigate the effects of acidic deposition on the park's ecosystems.



and causes the release of toxic aluminum that can harm vegetation and stream life. Sensitive mountain streams and forest soils are being acidified to the point that the health of the park's high elevation ecosystems are in jeopardy. Results of atmospheric deposition monitoring at the park show that annual wet nitrogen deposition between 1981 and 1999 increased 22 percent, while calcium deposition over the same period decreased by 24 percent, as shown in the figure below. Less calcium deposited in the park may also contribute to less nutrients for aquatic and terrestrial systems. Given the documented effects on park ecosystems and the continuing rise in many constituents of atmospheric deposition, large reductions in nitrogen and sulfur emissions are necessary to protect sensitive streams and soils in the park.





Several trends in wet deposition levels have park managers concerned. Total nitrogen deposition and nitrate in precipitation increased from 1981-1999. Decreased calcium deposition could result in fewer nutrients being available for aquatic and terrestrial ecosystems. Although sulfate levels in precipitation declined significantly, further reduction in sulfate is needed to restore ecosystems adversely impacted by atmospheric deposition to their natural condition.

Ozone pollution and its impacts

Ground-level ozone, produced by the reaction of nitrogen oxides and volatile organic compounds (VOCs) in the presence of sunlight, is one of the most widespread pollutants affecting vegetation and public health in the eastern U.S. Power plants, cars, trucks, and factories are the main emitters of nitrogen oxides, whereas VOCs are emitted by vehicles and by industry. VOCs (primarily isoprene) are also emitted by vegetation, including trees that are common to the eastern U.S. These natural emissions exceed human-caused emissions during the summer. However, with the addition of emissions associated with human activities, ozone levels can rise substantially above background levels of 20 to 40 parts per billion.

From a resource protection perspective, high ozone levels at Great Smoky Mountains National Park have been a concern since the 1970s when foliar injury symptoms consistent with ozone injury were first documented. In the late 1980s, Great Smoky Mountains NP researchers teamed with EPA and other researchers to confirm these earlier reports and identify those vegetative species susceptible to ozone injury and to quantify the relationship between ozone levels and effects, such as foliar injury and biomass loss. Based on these controlled experiments conducted at the park (see figure at right), 25 of 39 native species tested showed injury similar to that observed in the park indicating that vegetation throughout the park was being damaged by ambient levels of ozone. In a separate study conducted in the early 1990s, researchers found ozone foliar injury on black cherry, yellow poplar, and sassafras trees in the vicinity of three of the park's ozone monitoring stations. Ozone injury increased with increasing elevation and ozone exposure, indicating that vegetation on mountain tops and ridges were likely more susceptible to ozone injury. From these investigations, 30 species of plants have shown leaf damage after being exposed to controlled ozone levels identical to those that occur in the park, and an additional 60 species have been identified that exhibit ozone-like symptoms. Sensitive species like black cherry and yellow poplar show both visible injury and significant growth reductions due to ambient ozone. Failure to show visible injury is not indicative of a plant not being injured, as reduced photosyn-

Researchers use fumigation chambers such as these to expose different plant species to varying amounts of ozone pollution in order to document the type of injury or damage that occurs from different levels of exposure. This type of experiment was used to determine which types of plants were being affected by ozone pollution at Great Smoky Mountains National Park. Nearly 100 different species of plants have shown ozone-like injury symptoms.

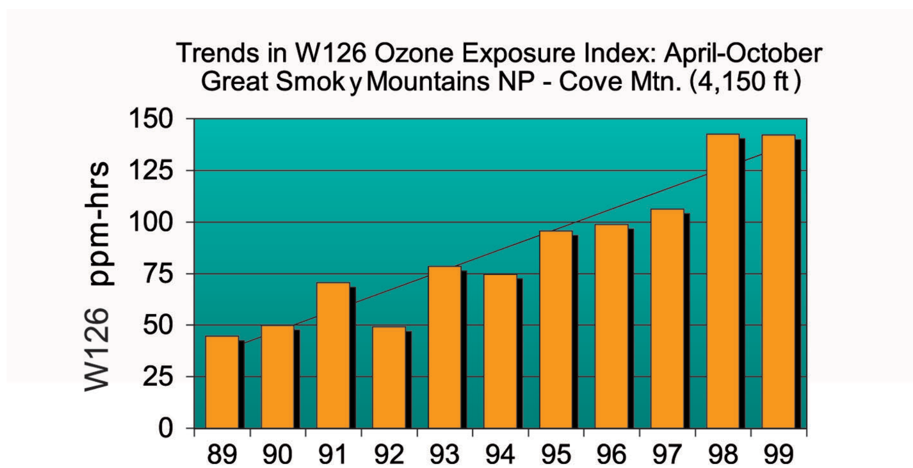
How Ozone Injures Plants

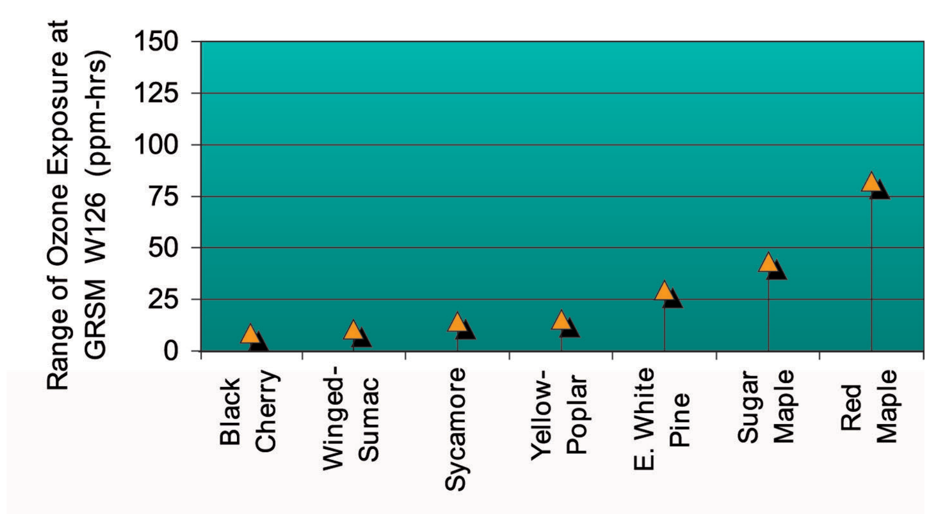
Ozone enters plant leaves through small openings called stomates during normal photosynthesis. Once inside the leaf, ozone changes the integrity of cells. Cells collapse and die and visible symptoms can occur on upper leaf surfaces. Depending on the type and variety of the plant, the concentration and duration of ozone, and other environmental factors, ozone can cause an array of symptoms in plants. The injury usually manifests itself as small necrotic areas or stippling, change in pigmentation, chlorosis from chlorophyll breakdown, and premature aging and senescence. These types of visible injury can lead to changes in physiology and growth.

Examples of healthy (left) and injured (right) foliage from ozone exposure are illustrated by the two species pictured: black cherry (top) and tall milkweed (bottom).

thesis or growth reductions could be occurring in the absence of any visible injury.

Ozone exposure indices that are calculated by summing ozone concentrations over a specified period of time (for example, a month or an entire summer) are often used to relate ozone levels to ozone injury to vegetation. Some researchers use an exposure index known as W126 that is similar to the SUM06 discussed in Chapter Two. As illustrated in the graphs below, different species of trees native to the park show a large variability in the level of ozone exposure (W126) that causes a 10 percent growth reduction. Black cherry, for example, is extremely sensitive to ozone and can be damaged at rather low levels of exposure. Sugar and red maples, on the other hand, require much higher exposures to inhibit growth. The figure below also illustrates how ozone exposure levels at the park, as recorded at the Cove Mountain site, have risen rather dramatically since 1989 implying that injury to vegetation has also increased during this same time period. In fact, researchers have found a 12 percent reduction in radial growth over 5 years, and 8 percent over 10 years, in black cherry in the park. For yellow poplars, the reduction has been much greater, 43 percent over 5 years and 30 percent over 10 years.

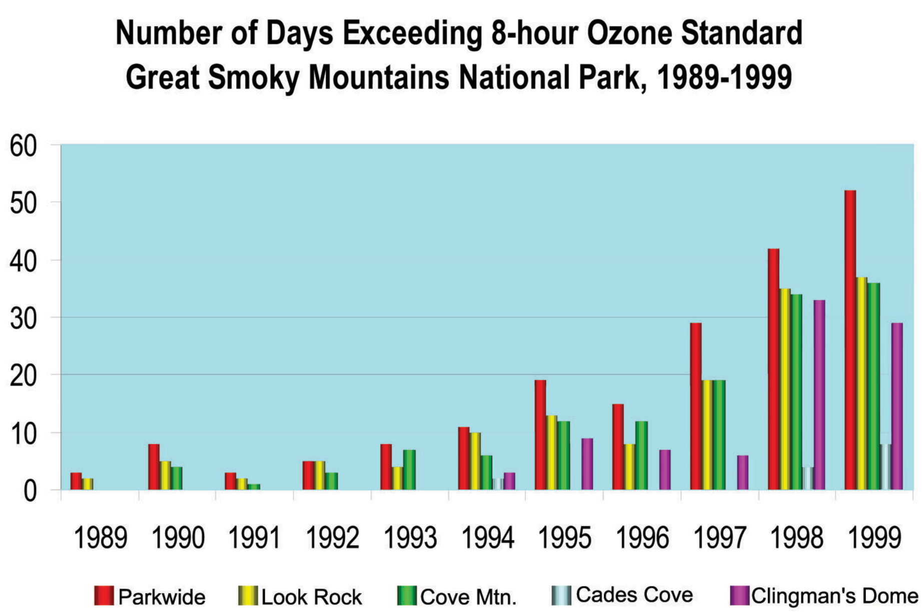




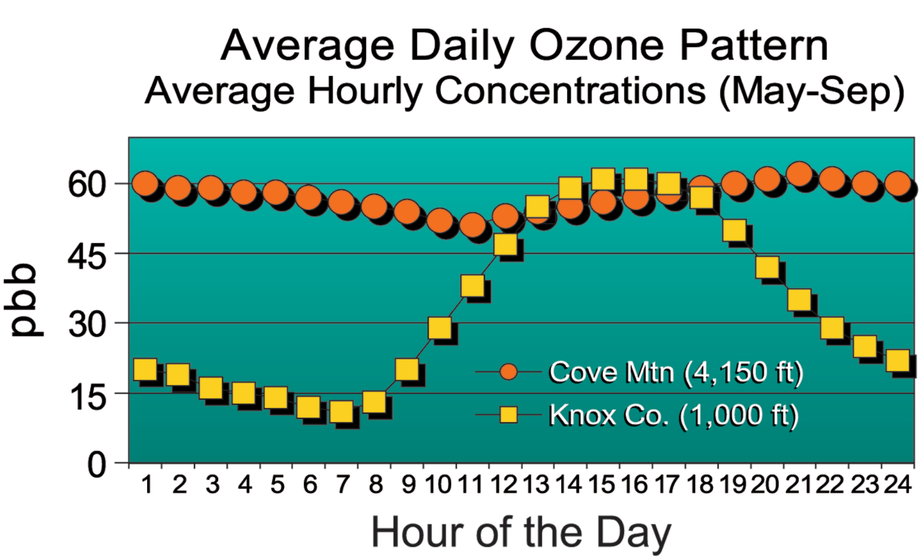
Ozone exposures at Great Smoky Mountains National Park, which typically exceed the injury level for numerous plant species, increased steadily between 1989 and 1999 (top graph). The bottom graph shows the ozone exposure levels associated with a 10 percent growth reduction in seedlings for various native plant species, based on fumigation chamber studies conducted at the park. Various plant species showed growth reductions at very low levels of exposure.

Ozone monitoring conducted at five locations in the park has shown that ozone exposures are among the highest in the eastern U.S. Levels have exceeded EPA's 1-hour and 8-hour ambient air quality standards set to protect public health. The figure below illustrates the sharp rise in the number of times the maximum 8-hour ozone concentration has exceeded the EPA 8-hour standard in the park. Three locations, Clingman's Dome, Cove Mountain, and Look Rock, recorded over 30 days above the 8-hour health standard in 1998 and 1999. Most ozone pollution measured at the park is transported from large urban areas in the southeastern U.S., such as Knoxville, TN, and Atlanta, GA.

Ozone is a powerful respiratory irritant for humans. Research shows that ozone can cause coughing, sinus inflammation, chest pains, scratchy throats, permanent damage to lung tissue, and reduced immune system functions. Children, the elderly, those with pre-existing respiratory and pulmonary problems, and healthy adults engaged in strenuous outdoor activities are most vulnerable. The park recorded 52 unhealthy ozone days in 1999, the second highest total for any location in the eastern U.S., second only to Atlanta, GA. The park now issues ozone advisories to visitors, staff, and the media on the high ozone days, recommending that people take precautions and reduce their exposures by hiking or working at lower elevations and taking frequent breaks.



The number of days with ozone levels above the national ambient air quality standard have risen sharply since 1989 posing threats to vegetation, as well as park visitors and employees. The "Parkwide" column represents the total number of separate days that at least one monitoring location exceeded the standard. In 1999, the park recorded 52 "unhealthy" days that exceeded the standard. High ozone levels are typically recorded during the summer. Regional pollution control strategies are necessary to improve air quality.



Average daily ozone patterns at Great Smoky Mountains National Park and Knoxville, Tennessee. Higher elevation sites at the park are constantly exposed to high ozone levels throughout the day. In contrast, when areas show a characteristic diurnal pattern in ozone levels with peaks occurring in mid-afternoon. The depletion of ozone in urban areas at night results from the destruction of ozone by nitrogen oxides emitted by automobiles.

Air Quality Monitoring at Great Smoky Mountains National Park

<u>Precipitation Chemistry Monitoring</u> [1]
Elkmont (elev. 2,100 ft) ongoing since 1980
Noland Divide (elev. 5,700 ft) ongoing since 1985

<u>Dry Deposition Monitoring</u> [2]
Look Rock (elev. 2,700 ft) ongoing since 1998
Clingman's Dome (elev. 6,670 ft) ongoing since 1996

<u>Cloudwater Chemistry Monitoring</u> [2]
Clingman's Dome - ongoing since 1994

<u>Visibility and Fine Particle Monitoring</u> [3]
Look Rock - ongoing since 1984
Cove Mountain (elev. 4,150 ft) since 2000

<u>Ozone, other gaseous pollutants, Meteorology</u> [4]
Look Rock - ongoing since 1984
Cove Mountain - ongoing since 1986
Clingman's Dome - ongoing since 1993
Cades Cove (elev. 1,850 ft) - ongoing since 1994
Purchase Knob (elev. 4,900 ft) - ongoing since 1995
Twin Creeks (elev. 2,000 ft) 1987-1995

<u>Mercury Deposition Monitoring</u> [1]
Elkmont 2002-
Clingman's Dome 2002-

<u>EPA UVB Monitoring</u>
Cades Cove - ongoing since 1998

[1] *As part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN)*
[2] *As part of EPA's Clean Air Status and Trends Network (CASTNet)*
[3] *As part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) network*
[4] *As part of NPS air quality monitoring network*

Most monitoring activities at the park are coordinated through the NPS Air Resources Division

Using volunteers in the air quality monitoring and research program is one way of obtaining air pollution information.

Air quality monitoring and research activities

Great Smoky Mountains National Park prides itself in having a comprehensive air quality monitoring and research program that is a major component of the park's overall natural resource management program. This is a result of the vital importance of air quality to many of the resources for which the park is noted. The goals of the program are to:

- Determine the status and trends of pollutant concentrations in the ambient environment
- Determine the effects of air pollutants on park resources
- Determine the sources of pollutants affecting park resources

Since the early 1980s, an extensive network of air and water quality monitoring stations has been established in the park to assess the status and trends of several key pollutants or conditions. The air monitoring program includes gaseous pollutants (ozone, sulfur dioxide, carbon monoxide, and nitrogen oxides), visibility, fine particle, precipitation chemistry, and meteorological monitoring. Long-term monitoring and research data collected at Great Smoky Mountains National Park have allowed the park to document the status and trends of important air quality indicators and the effects that airborne pollutants are having on the park's terrestrial, aquatic, and scenic resources.

Cooperative research efforts with other government agencies have also allowed for a greater understanding of the probable causes of air pollution effects being observed, the transport pathways for pollutants reaching the park, and the atmospheric chemistry or mechanisms associated with poor air quality.

Southeastern Aerosol and Visibility Study (SEAVS) Particle data, such as that collected by the IMPROVE visibility network, have routinely been used to provide a measurement of visibility conditions. Historically, the haziest conditions have been underestimated by 30 percent to 50 percent in the eastern U.S. using these data. The contribution that fine particles have on visibility reduction is very dependent on the amount of water absorbed by some of the chemical constituents of these particles and their physical and chemical properties. Using the intensive measurements made at the park various mathematical models were applied to estimate light extinction. The study revealed that sulfate aerosols are more acidic than previously believed thereby causing greater reductions to visibility during some episodes. This resolved a major limitation in estimating light scattering from fine particle measurements. By properly accounting for aerosol acidity, better predictions can be made on how changes in emissions, such as those required by the Clean Air Act, will translate into changes in haziness at the park and throughout the eastern U.S.

Park Research and Intensive Monitoring of Ecosystems Network (PRIMENet) In 1996, the EPA and the NPS agreed to use 14 national parks, including Great Smoky Mountains, as "outdoor laboratories" to examine trends in global and regional environmental stressors, such as air pollutants and UV-B radiation, and the response of natural systems and populations to these stressors. Findings from this research will guide NPS managers in making science-based decisions related to the protection and preservation of park natural resources. Activities from this effort will enable park scientists to scale atmospheric deposition measurements made at one location to entire landscapes using tools like a geographic information system (GIS). Two methods are being investigated to characterize the deposition-terrain response fields: sulfate fluxes in through-fall and lead in surface soils, which have been shown to be excellent tracers of primary deposition processes. This project represents a crucial step in atmospheric deposition research at the park and important for the management of ecosystems exposed to acid deposition.

Research on ozone damage to the growth and physiology of native trees and wildflowers Research on the effects of ozone pollution on vegetation has occurred at Great Smoky Mountains for nearly 20 years and has contributed to what is known nationally about its effects on native vegetation. New research is focusing on the impacts of ozone on selected tree and wildflower species found in the park. In addition, researchers hope to learn how historical ozone levels and climate variations have affected tree growth by examining tree rings. Measurements of visible ozone injury on native wildflowers and trees will be made to determine differences in species sensitivity and if injury varies by location. Information derived from this and previous investigations is useful in establishing air quality standards that adequately protect park vegetation.

Southern Appalachian Mountains Initiative (SAMI) SAMI, started in 1992, is a broad-based effort focusing on regional air quality and its effects on natural resources of the Southern Appalachian Mountains. SAMI conducted an integrated assessment modeling of the effects of air pollution (haze, ozone, and acid deposition) on streams, soils, forests, and visibility, with particular attention to the 10 Class I national parks and wilderness areas in the region. SAMI brought together representatives from state and federal agencies, industries, environmental groups, academia, and the interested public to identify and recommend emissions management strategies. It is hoped that these strategies when implemented will remedy existing impacts and prevent future impacts for the eight states surrounding the Southern Appalachian Mountains: Alabama, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia.

Public awareness: a key to success
This challenging regional air pollution problem at Great Smoky Mountains National Park was brought to the forefront at the beginning of the 1990s and has continued to grow. Lacking authority under the Clean Air Act to regulate new or existing pollution sources directly, Great Smoky Mountains National Park uses the information and tools that are available to influence and convince regulatory authorities, governmental and industry officials, and the public, that action must be taken to clean up the air. The park has reached out to all stakeholders to ensure that they are aware of the scientific information gathered and of the resource protection issues facing the park. The management and staff of Great Smoky Mountains National Park have confronted this challenge head-on and have become a forceful advocate for clean air throughout the entire region surrounding the park. This has been done by successfully leveraging limited NPS funds to acquire the necessary data documenting resource damage and the need for pollution reductions. Key to this effort is an aggressive, comprehensive educational effort to communicate the air quality issues in a way that is understandable to the public and governmental officials.

Partnerships
Increasing public awareness and understanding of pollution problems in Great Smoky Mountains National Park has been successful by building strong partnerships at the local, state, and federal levels. The park's air quality management program is actively involved with the people engaged in air quality management, including citizen's groups, individuals, industry, and various levels of government. These include city and county officials, state, regional, and national legislators and policymakers. In addition the park has partnered successfully with numerous scientists, universities, and other researchers to develop the science base needed to deal effectively with air pollution issues.

Public awareness and education: "keep telling the story"
Park staff has made the case for improved air quality succinctly and consistently over the years. It has identified and suggested strategies to remedy the air quality problems facing the park. Great Smoky Mountains National Park's air quality program has increased credibility for the National Park Service's air resource management program that has produced broad-based public support for clean air not only for the Smokies but also for all our national parks.

Specific areas where Great Smoky Mountains National Park has been successful in enhancing public awareness of air quality issues facing the park include:

- Participating in one of the most extensive monitoring networks and research programs in the National Park Service with some of the highest quality data available

- Distribution of air quality background materials and publications

NPS Director Fran Mainella (far left) listens to Air Resource Management Specialist, Jim Renfro, as he discusses the effects that air pollution is having at Great Smoky Mountains National Park. The park uses information gathered by its air quality monitoring and research program to inform NPS management, state and federal officials, and the public as to why air quality is such an important park resource.

Production of interpretive materials, such as numerous wayside exhibits, a real-time Internet-accessible air quality display at Sugarland Visitor Center, and an interactive CD-ROM touch-screen exhibit at Oconaluftee Visitor Center are available.

- Maintenance of a Web site displaying real-time air quality conditions and describing air pollution problems at the park *(http://www2.nature.nps.gov/ard/parks/grsm/grsmcam/grsmcam.htm)*.

- Implementation of an ozone advisory program to inform visitors of unhealthy air quality, whenever it occurs at the park

- Highlighting air pollution issues at the park in the park's orientation film

- Sponsorship of a "Parks-as-Classrooms" program teaching thousands of children annually about air pollution issues at the park

- Providing information to local and area Clean Air Campaigns

- Providing air quality monitoring "report cards" to a variety of stakeholders including governors, members of Congress, local leaders, media, scientists, staff, and environmental and industrial stakeholders

- Assisting states and industry in assessing the potential impacts of new air pollution sources on park resources to satisfy permit issuance requirements

All of these efforts are paying dividends in getting the public and decision-makers to understand why good air quality is vital not only to the park but also to the region as a whole. Only through public understanding of the air pollution issues facing the park and region, and making sound, science-based decisions will we be able to remedy existing and prevent future adverse impacts at Great Smoky Mountains National Park. Pristine views occur when the air is free of airborne pollutants.

Example Web page for Great Smoky Mountains National Park displaying near real-time image, ozone, and weather conditions.